national accelerator laboratory

EXP-16

July 6, 1972

ACCELERATOR EXPERIMENT--Momentum Spread in Main-Ring Beam and Increasing Momentum Spread by Running on Unstable rf Phase

Experimentalists: H. Edwards, J. Griffin, R. Stiening, *et.al.*

Date Performed: 7/6/72

Measurement and Analysis:

1. The momentum spread in the main-ring beam at 100 GeV was measured by observing the debunching time when the rf is turned off on the flat-top. The observed data are

bunch length with rf on (observed using the strip-line detector) = 2.5 nsec

= 48° (rf period = 18.8 nsec = 360°)

debunching time to lenghthen 2.5 nsec to 18.8 nsec ≅ 50 msec, hence

$$\text{debunching rate} = \frac{(18.8 - 2.5)\ \text{nsec}}{50\ \text{msec}} = 330\ \text{nsec/sec.}$$

The computed debunching rate at 100 GeV is 250 nsec/sec for a total $\frac{\Delta p}{p}$ of 10^{-4}. Therefore, the measured debunching rate gives

$$\frac{\Delta p}{p} = \frac{330}{250} \times 10^{-4} = 1.3 \times 10^{-4}.$$

If the momentum spread of the linac beam at 200 MeV is $\frac{\Delta p}{p} = 2 \times 10^{-3}$ and if the longitudinal emittance is conserved throughout (100% rf capture and no emittance blow-up by rf noise) we get at 100 GeV

$$\frac{\Delta p}{p} = 1.15 \times 10^{-4}.$$

The agreement is probably fortuitous.

2. The rf phase is then jumped on the 100 GeV flat-top so that the beam bunch sits on the unstable synchronous phase. After various durations (Δt) of running on the unstable phase the beam radial width was observed on the ion-profile detector (located at $x_p \cong 4$m). The bunch length was also observed on the ferrite detector. But the slow response of the ferrite detector makes the bunch length observation questionable. The rf voltage is 1.2 MV. The observed data are given in Table 1.

Table 1

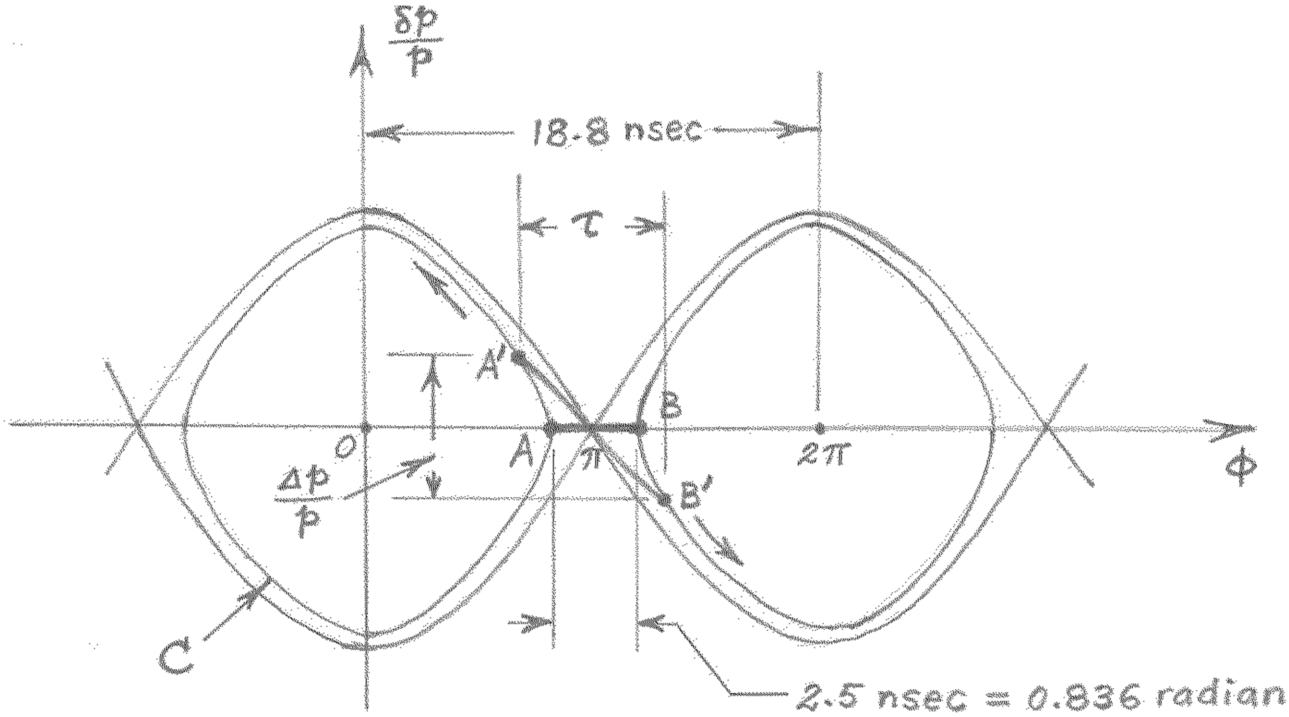
Δt (msec)	bunch length (nsec)	beam radial width (mm)	$\frac{\Delta p}{p}$
0	2.5	13	0.13×10^{-3}
2.5	8	16	0.9×10^{-3}
5.0	-	21	2.1×10^{-3}
87.5	-	44	7.9×10^{-3}

where $\frac{\Delta p}{p}$ in the last column is computed from the beam radial width using $x_p = 4$m and assuming the betatron-oscillation width to be

$$13 \text{ mm} - x_p \frac{\Delta p}{p} = 13 \text{ mm} - 4 \text{ m} \times (0.13 \times 10^{-3}) = 12.5 \text{ mm}$$

because $\frac{\Delta p}{p} = 0.13 \times 10^{-3}$ at $\Delta t = 0$ as measured by part (1) of the experiment. In the last row the beam is way outside of the rf bucket.

When the beam bunch is sitting on the unstable synchronous phase of stationary buckets the phase diagram looks like



At $\Delta t = 0$ the beam bunch with length 2.5 nsec is shown as AB with zero $\frac{\Delta p}{p}$. After a finite Δt the bunch is stretched out to A'B' with length τ.

The equation of the trajectory curve C is

$$\left(\frac{\delta p}{p}\right)^2 + \frac{1}{\pi h} \frac{eV}{mc^2} \frac{\gamma}{\gamma^2 - 1} \frac{\cos \phi}{\left(\frac{1}{\gamma^2} - \frac{1}{\gamma_t^2}\right)} = \text{const}$$

where the constant on the right-hand side is adjusted so that the curve passes through point A at $\phi = \pi - 0.418$ and $\frac{\Delta p}{p} = 0$. With

h = harmonic number = 1113
γ_t = transition γ = 19.6
V = rf voltage = 1.2 MV

numerically we have at 100 GeV

$$\frac{\Delta p}{p} = 2\frac{\delta p}{p} = 2.326\text{x}10^{-3}\ (0.914+\cos\phi)^{1/2}$$

where

$$\phi = \pi\left(1 - \frac{\tau}{18.8}\right). \qquad \tau \text{ in nsec}$$

For various beam bunch length τ we get

τ (nsec)	$\frac{\Delta p}{p}$ (10^{-3})
2.5	0 (or $0.13\text{x}10^{-3}$)
4	0.8
6	1.43
8	1.92
10	2.34
12	2.69
14	2.95
16	3.13
18.8	3.22

Thus, we see that for $\frac{\Delta p}{p} = 0.9 \times 10^{-3}$ the bunch length should be ~4.2 nsec instead of the 8 nsec as observed using the slow ferrite detector.

The traversal speed along curve C is extremely nonlinear. It is perhaps not worth the effort to compute the time Δt to check with the values given in Table 1. Since the period of a small phase oscillation is about 11 msec the Δt values in Table 1 look entirely reasonable.

One concludes, therefore, that this is a usable scheme to enlarge $\frac{\Delta p}{p}$ for smoother beam spill using resonant extraction.

L. C. Teng